Theoretical Consideration on the Deformation and Stress of Island-Arc Crust

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The deformation of island-arc crust is caused partly by plate-to-plate interaction and partly by brittle fracture and/or ductile deformation in the crust. The deformation due to plate-to-plate interaction is elastic everywhere except plate boundaries. On the other hand, the deformation due to brittle fracture and/or ductile deformation in the crust are elastic and inelastic.

The plate-to-plate interaction can be rationally represented by the increase of tangential displacement discontinuity (fault slip) at plate interfaces (Matsu'ura & Sato, 1989). The fault slip is mathematically equivalent to a moment tensor (Backus & Mulcahy, 1976), the spatial derivatives of which give the force system that deforms island-arc crust elastically. Since back slip does not occur at plate interfaces, the elastic deformation of island-arc crust due to plate-to-plate interaction increases with time on long-term average. It should be noted that the increase of elastic deformation means the increase of stress in the crust. The patterns of stress increase rates significantly differ region-by-region, reflecting difference in plate-to-plate interaction. The regional difference in plate-to-plate interaction can be quantitatively described by defining the partial collision rate as 1 - interplate-slip-rate/plate-convergence-rate (Hashimoto & Matsu'ura, 2006). In the case of simple plate subduction with zero partial collision rates, the stress increase rate due to plate-to-plate interaction is very slow, and so we may consider the crust to be almost in a steady stress state. In the case of positive partial collision rates (e.g., Himalaya with persistent slip-rate deficit) or negative partial collision rates (e.g., Mariana with persistent slip-rate excess), the plate-to-plate interaction increases a certain pattern of crustal stress at a constant rate. In the latter case, since the strength of the crust is finite, the accumulated stress must be eventually released somewhere.

The crustal stress caused by plate-to-plate interaction is released by the brittle fracture and/or ductile deformation of a number of preexisting cracks and faults in the crust. The occurrence of brittle fracture and ductile deformation is always accompanied by the generation of inelastic strain. The generation of inelastic strain can be represented by an equivalent moment tensor, which gives the force system that brings about elastic deformation in the region surrounding the source. The brittle fracture and ductile deformation occur so as to decrease the potential energy of the crust under the energy balance equation, which is the stress release process as proved from the volume integral representation of a moment tensor, and also the conversion process of widely distributed elastic strain to local inelastic strain as proved from the potency conservation equation. Through this process, while the stress and potential energy are released, but the amount of strain is conserved. Thus, we can conclude that the deformation-concentrated zone is the heap of inelastic strain converted from the crustal elastic strain caused by plate-to-plate interaction through brittle fracture and/or ductile deformation over a longtime period.